

## **EVALUATION OF PAVEMENT MARKINGS UNDER WET-NIGHT ROAD CONDITIONS BEST PRACTICES STUDY**

**Prepared For:**

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## **LIST OF ACRONYMS**

AASHTO	American Association of State Highway and Transportation Officials
ADT	Average Daily Traffic
CALTRANS	California Department of Transportation
DOT	Department of Transportation
FHWA	Federal Highway Administration
LED	Light-Emitting Diode
MUTCD	Manual on Uniform Traffic Control Devices
OGSC	Open-Graded Surface Course
PCC	Portland Cement Concrete
ROI	Return on Investment
STIP	Statewide Transportation Improvement Program (UDOT)
TAC	Technical Advisory Committee
TTI	Texas A&M Transportation Institute
UDOT	Utah Department of Transportation
UTL	Utah Traffic Lab (University of Utah)
UTRAC	Utah Transportation Research Advisory Council
VTRC	Virginia Transportation Research Council

## **EXECUTIVE SUMMARY**

This study was conducted on behalf of the Utah Department of Transportation (UDOT), with a purpose to identify best practices by other governmental agencies in comparison to UDOT's current practices for the selection of pavement marking materials and products. In particular there was an emphasis to identify practices by other agencies and/or emerging technologies that could be used to improve pavement marking visibility during wet-night conditions.

The study was conducted by private engineering management consulting firms on behalf of UDOT's Research Division. A technical advisory group was used with representation from several technical areas within UDOT, including: Research, Planning, Traffic & Safety, Materials, Maintenance, and Preconstruction (design).

The goal of the study was to review UDOT's current practices in comparison to other governmental agencies, and emerging trends with an emphasis on all-weather pavement markings. The results of this study will be used to assist UDOT in an anticipated review and updating of its current Pavement Marking Decision Matrix.

The study began with a review of UDOT's current Pavement Marking Decision Matrix, standards, specifications, and processes. This was followed up with interviews of technical experts from divisions within UDOT including: Planning, Maintenance, Traffic & Safety, Materials, and Preconstruction (design). This was followed by a web based literature search to identify past studies that may be relevant to this study. A search of each State DOT's web page was conducted to identify their pavement marking decision practices. This was followed up by a short survey of each state.

The results of the study show that UDOT's current practice for the selection of pavement markings is primarily based on cost and durability with a goal of maximizing the efficient use of limited budgets. The majority of State agencies were found to follow a similar engineering economics approach using primarily a durability to cost (benefit to cost) approach.

However a few States were identified as having broader decision criteria that included consideration for other factors such as weather (climate), snow removal, accident histories, roadway geometrics, construction work zones, and functional classification. There is an opportunity for UDOT to expand its current decision matrix to include additional factors.

The study showed the ability to gather, retrieve and analyze data has dramatically improved over the past decade with continuously emerging and user friendly software and computer systems. UDOT has recently added two such software systems, Decision Lens for Planning and NuMetrics for Traffic and Safety data. This offers a significant opportunity for UDOT to use these software systems as it considers additional factors, while reviewing and updating its current Pavement Marking Decision Matrix.

The study identified that many States have either a Pavement Marking or Traffic and Safety Manual or Guidelines. Most of these are based on conformity to national standards such as the Manual for Uniform Traffic Control Devices (MUTCD). However a few states include broader material and product decisions in their manuals or guidelines. There is an opportunity for UDOT expand its current two page Decision Matrix to make it a part of a larger Pavement Marking Guide and/or a Traffic and Safety Manual.

The study showed a general trend that the governmental agencies that had the best documented processes and active research were also those that used a multi-disciplined approach with input from various technical areas. There is an opportunity to UDOT to improve communications by reintroducing its pavement marking committee, participate in national committees and leverage the work of other states with scanning tours and research.

Finally, the study identified that there are several new or emerging technologies with the opportunity to improve visibility in wet-night and all weather conditions. These include the use of Light Emitting Diode (LED) delineation, surface and material profiling to improve drainage (reflectivity), better bead technologies, and pavement grooving (recessed markings). Another emerging trend that was identified is current efforts worldwide to develop automated (driverless) vehicle systems. These automated vehicles will likely require additional changes in pavement marking design, signing and other recognizable roadway features. There is an opportunity for UDOT to conduct additional research, product evaluations, and test sections.

## **1.0 INTRODUCTION**

### **1.1 Problem Statement**

The Utah Department of Transportation (UDOT) has an established “Strategic Goals” initiative, which includes 3 key goals for the Department and its employees:

- *Zero Crashes, Injuries and Fatalities*
- *Preserve the Infrastructure*
- *Optimize Mobility*

UDOT Engineers recognize the importance that traffic and safety features play in supporting these broader goals of safety and mobility. This includes pavement marking delineation products and materials. From a public perspective, one of the greatest complaint topics that transportation agencies receive are requests for improved signing and striping. This is especially true during wet-night conditions.

UDOT’s Division of Research holds an Annual Research Workshop to identify and prioritize upcoming research activities. This brainstorming workshop is sponsored by the Utah Transportation Research Advisory Committee (UTRAC). One of the projects identified and selected for funding during the 2015 UTRAC workshop was this study to “Evaluate Best Practices of Pavement Markings under Wet-Night Conditions”. A copy of the Problem Statement used to propose this project during the workshop is included in Appendix A.

The information gathered in this study will be used to help UDOT further refine internal processes to select different pavement marking products and materials for a variety of conditions, and further evaluate emerging technologies.

This study was conducted on behalf of the Utah Department of Transportation – Division of Research with a Technical Advisory Committee (TAC) represented by experts from UDOT Maintenance, Traffic & Safety, Materials, Design, Research, and Planning Divisions.

Pavement marking delineation provides a key function in highway safety and the efficient flow of traffic. The absence of visible markings can lead to driver confusion, uncertainty of

hazards, erratic lane changes, high variations in speeds, and general frustration by the traveling public.

The visibility of pavement markings dramatically decreases during nighttime conditions. To be effective, current technologies rely on light being reflected back to the driver (retro-reflectivity). Reflective beads are commonly used to accomplish this. However, the effectiveness of the pavement markings reflectivity is substantially decreased with the deterioration or cleanliness of the beads and/or marking materials.

During wet weather conditions, the surface of the beads is often flooded by water, diffusing the light and reducing the visibility. During winter weather, the surface of the beads is often coated with deicing salt and chemicals that reduce reflectivity. Finally, the durability of the beads and marking materials are reduced by deterioration from tire abrasion, grit and snow removal operations.

This study was initiated in response to address these issues, with a goal to identify current research efforts, “best practices” used by other governmental agencies, and emerging technologies. The information gathered will be used to assist UDOT in reviewing its current pavement marking strategies for potential improvements.

## 1.2 Objectives and Scope

The overall objective of this study is to identify and quantify information from recent research, current practices used by other agencies, and emerging technologies. The specific objectives and deliverables include the following:

1. Conduct a comprehensive literature search, including non-U.S. research, from highway agencies and the transportation industry.

Deliverable: *Identify “best practices” used by other agencies, including any unique strategies specific to wet-night visibility including: rain, mist/fog, and winter conditions.*

2. Identify promising and emerging technologies including those specifically targeted to address nighttime and wet weather conditions.

Deliverable: *Prepare a list of recommended emerging technologies or practices for UDOT to consider.*

3. Identify and summarize a list of potential opportunities for UDOT to consider in reviewing its current pavement marking selection guide, including weather, traffic and durability considerations.

Deliverable: *Prepare a list of recommended improvements for consideration in updating UDOT’s current pavement marking selection guide.*

4. Provide recommendations for areas of further research, development and/or field evaluations to advance UDOT’s approach to wet-night visibility of markings.

Deliverable: *Prepare a list of recommendations for future research, test sections and implementation.*

## **2.0 RESEARCH METHODS**

### **2.1 Overview**

The study was structured to compile existing information gathered from a variety of existing sources that are relevant in selecting and maintaining pavement marking products and materials. In particular, the research study was targeted to identify best practices and experiences relating to wet weather – nighttime visibility of pavement markings.

Information regarding broader pavement marking practices is discussed as a comparison, but is not the primary focus of the study. Sources of information include: academic researchers, federal agencies, state departments of transportation, local government agencies, international agencies, and material/product suppliers.

To accomplish the objectives of the study, the following tasks were completed. The work approach and findings of each task are presented throughout this document, in addition to the findings and recommendations at the end of the report.

Task 1: Review of UDOT Current Practices

Task 2: Interviews with UDOT Technical Experts

Task 3: Identify Other Agency Practices

Task 4: Literature Search of Past Research Studies

Task 5: Identify Emerging Technologies

Task 6: Evaluate Opportunities to Improve Decision Matrix

Task 7: Recommendations

### **2.2 Background and Methodology**

Pavement marking delineation is an essential component of a highway's safety and mobility. Pavement marking systems need to be visible in a wide variety of applications and conditions. This includes wet weather and nighttime conditions. The effectiveness of the pavement marking systems is influenced by many factors including the weather conditions, products, pavement types, deterioration and wear over time. This study is intended to identify

and recommend best practices for selecting and maintaining pavement markings that are reliable under wet-night conditions.

Multiple methods for collecting data were used, including web searches, in-person interviews, informal phone calls, and a web-based survey, in order to collect as much information as possible from a variety of sources and to obtain a more accurate view of the current pavement marking practices of UDOT in comparison to other governmental agencies.

The study was intended to serve as “applied research” with the results of the qualitative information gathered to be used to assist UDOT in a review of its current practices. It was not intended to be a “basic research” study with common quantitative, cause and effect, or statistical approaches. However, many of the findings and observations are presented in measurable ways.

#### 2.2.1 Methodology used to Identify Current UDOT Practices

The first steps of this study (Tasks 1 and 2) involved reviewing UDOT’s current pavement marking practices and interviewing UDOT’s technical experts. Standards, specifications, policies and procedures, and UDOT’s pavement marking decision matrix were reviewed. This was followed up by informal interviews with technical experts from UDOT’s Planning, Traffic and Safety, Materials, and Maintenance Divisions. This helped to gain a better understanding of concerns, unmet needs and how current practices are used.

#### 2.2.2 Methodology used to Identify Other Agency Practices

Information on the practices of other agencies was first gathered through searches of each State DOT’s webpages. In particular, information relating to pavement marking policies, standards and guidelines was sought. This included looking for how pavement marking products were selected under varied conditions. Many agency webpages are targeted to provide high level information to the public, consultants, and contractors. As a result, many state DOT web pages do not go into great detail of specific product uses such as pavement marking guidelines. As a result, a follow-up questionnaire was distributed by email to each state and the members of the AASHTO Subcommittee on Transportation Engineering, which includes members from all states. The survey was not designed to provide a statistical analysis of data, but did confirm previously found information or where to look.

### 2.2.3 Methodology to Identify Past Research Studies and Emerging Technologies

Tasks 4 and 5 included a literature search to identify formal research and development studies relating to wet-night pavement marking visibility along with emerging technologies relating to pavement markings and delineation. Web searches and informal phone calls were used to identify past research reports. Sources of information for emerging technologies included pavement marking product suppliers, governmental agencies, academic researchers and literature searches.

## **2.3 Summary**

Information regarding the practices used for pavement markings under wet-night conditions was successfully gathered from a variety of sources including academic research, governmental agencies and suppliers. The information was identified and collected using web-page searches, in-person interviews, literature searches, and questionnaires.

The research study provides valuable information and an opportunity to assist UDOT in its desire to review and update its current pavement marking decision matrix to include additional factors such as wet-night conditions. In addition, the information can serve as a baseline to validate current practices and consider future research and test sections.

## **3.0 DATA COLLECTION**

### **3.1 Overview**

Several tasks were used to collect existing data and information relating to pavement marking strategies and decision making used to select different products and materials under a variety of environments and applications. Information for wet-night conditions was an emphasis. The following tasks were used to collect the data and information:

### **3.2 Task 1: Review of Current UDOT Practices**

This study began with an initial task to review UDOT's current practices, policies and procedures used to make decisions for using different pavement marking materials and products under a variety of conditions. The approach to this task included interviews with UDOT engineers combined with a review of existing standards, specifications, and policies. The following is a summary of the findings for this task.

#### **3.2.1 UDOT Pavement Marking Decision Matrix**

UDOT currently uses a "Pavement Marking Decision Matrix", last updated in February 2013 (see Appendix B). The decision matrix is separate from standard specifications and standard drawings. It is intended as a "guideline", with the purpose of assisting designers and maintenance engineers with the selection of pavement marking materials. It is not a formal policy or requirement.

The current Pavement Marking Decision Matrix uses an asset management or engineering economic modeling approach. It is financially based with a benefit to cost (or return on investment – ROI), methodology that maximizes the efficient use of limited budgets. In particular, UDOT's current decision matrix was developed using retroreflectivity data and technical expert opinion combined with historical data of a materials cost to its durable life to obtain a cost per year. The cost component considers the installed price including labor,

equipment and materials. The durability component considers the life of the material based on minimum retro-reflectivity thresholds, bond to pavement and color stability.

UDOT's current pavement marking decision matrix has worked well over the years in maximizing the efficient use of limited budgets. It has long been recognized that the durability of pavement marking materials are directly related to traffic volumes (abrasion) and pavement type (bonding). As a result, the current matrix matches pavement marking products to pavement type and traffic volumes (AADT).

However, while beneficial in maximizing the efficient use of limited funding, the current decision matrix is limited in that it does not include other qualitative factors such as safety, climate, and the unique needs of a specific location. Recent research (see other sections of report) supports the consideration of additional factors such as safety and climate.

There is an opportunity for UDOT to consider additional factors as they move forward in reviewing and updating their pavement marking decision matrix. These factors could include issues such wet-night visibility, crash data, and snow removal areas.

### 3.2.2 Standards and Specifications

The study continued with a cursory review of UDOT's standards and specifications relating to pavement marking materials and products. It was found that the standards and specifications were driven primarily for the installation as a part of a larger construction project. The specifications typically refer to the quality of the materials and installation along with compliance to national standards included in the Manual for Uniform Traffic Control Devices (MUTCD), with slight variations for local preferences.

One of the key observations is that UDOT's standards and specifications are targeted to private contractors placing pavement marking materials. In comparison, UDOT maintenance crews also place pavement markings, using material procurement specifications that do not always match with construction specifications. In addition, maintenance procurement specifications do not require the quality review of installation the same as contract work. .

Both the standard construction specifications and procurement specifications are written in a generic nature so as to not favor a specific brand or product. UDOT uses an “Approved Suppliers List”, making it easier for contractors to choose products that are known to meet the generic specifications. UDOT also requires a warranty on some materials. There may be an opportunity to expand the use of an Approved Suppliers List to procurement specifications.

The construction specifications have some references to the use of pavement markings in construction work zones, but the requirements are limited. Finally, the standard drawings do reference the use of pavement grooving (inlaid) to increase durability.

### 3.2.3 UDOT – Current Pavement Marking Research Efforts

UDOT has been very proactive in remaining current in the pavement marking research and technologies. Over the past decade they have conducted numerous studies relating to durability, retroreflectivity, warrant specifications, installation practices and numerous test sections. This internal research information should be combined with the results of this study when evaluating potential changes to the current pavement marking selection guide. Some of these studies include:



**Figure 1 – UDOT Research Test Section**

- Useful life of Pavement Marking Materials – TranSafety 1996
- UT- 08.12 – Field Comparison of Five Pavement Marking Removal Technologies.
- UT – 10.05 – Failure of Surface Courses Beneath Pavement Markings
- UT – 13.16 – Lessons Learned – Pavement Marking Warranty Contract
- Test Section – I-84 Inlaid Pavement Grooving of Recessed Pavement Markings
- Test Section – SR6 – Painted Center Rumble Strips to Increase Marking Visibility

### **3.3 Task 2: Interviews with UDOT Technical Experts**

This study included informal interviews with technical experts from several divisions within UDOT. Input was sought from professional experts within the Planning, Traffic and Safety, Materials, and Maintenance divisions. Each of these technical areas expressed a strong interest in pavement marking decisions, with different perspectives depending on their respective technical areas. Collectively, an efficient coordination among these different groups offers the best opportunities to provide a balanced and comprehensive approach to decision making. The following is a summary of some of the relevant feedback from each of the technical areas:

#### **3.3.1 UDOT Traffic and Safety Division**

An interview was conducted with W. Scott Jones, P.E, of UDOT's Traffic and Safety Division, identifying several insightful thoughts. Key among these was a lead he provided to a recent (2015) FHWA study that quantifies the benefits of improving traffic and safety features to reduce accidents. In particular, it demonstrates the benefits of improved visibility under wet-night conditions. The study is discussed in greater detail later in the literature search section of the report.

Mr. Jones also provided an update of a recent (2015) effort of UDOT to contract with a private software company (Nu-Metrics, Inc.) to develop a software program to simplify the access to traffic and accident data. In particular, the software provides a user friendly method for non-traffic engineers to access historical accident data.

The easy access to this crash information provides a significant opportunity to consider additional factors in selecting pavement markings such as: crash data in comparison to factors such as location, weather conditions, time of day, roadway geometry and traffic characteristics. Information can be quantitatively evaluated based on specific goals such as cross asset funding, system wide pavement marking strategies, corridor studies, or project scoping.

### 3.3.2 UDOT Asset Management Division

Interviews with UDOT's Asset Management Division (John Thomas, PE), identified another perspective. In particular, Planners tend to take a broader asset management approach with an understanding that limited funds often require the choice of how to best allocate among many assets. Funds spend on one asset group, often reduce available funds for the upkeep of another asset. This choice of choosing funding of one alternative over another is commonly referred to as an "opportunity cost".

This leads to a series of questions relating to wet-night pavement markings. Should more money be spent on pavement markings over signing, attenuation or other safety features? Are risks higher for wet-night pavement marking needs than other traffic/safety concerns such as signals, geometric improvements, attenuation, signing, etc.? Should funding be moved from another need category to address wet night conditions? Are there products or materials that perform better than others?

UDOT's Planning & Programming Division is often challenged with similar questions from other asset groups and technical managers, each with their respective areas of expertise or responsibility. Managers are passionate in requesting increases to their budgets for individual programs. To respond to these competing needs and limited budgets, UDOT has effectively used an asset management approach in developing its Statewide Transportation Improvement Program (STIP).

To assist with its asset management and STIP planning and decision efforts, UDOT's Asset Management Division recently implemented the use of a new decision making software program marketed under the name "***Decision Lens***". In simplified terms, the software provides a computer based methodology to capture the experiences of technical experts, providing a qualitative and quantitative approach to prioritizing competing needs and interests. In many ways, it works similar to a Value Engineering process, but is software based. Participants provide responses anonymously and independently, which helps to reduce a common "group-think" bias in the outcome.

Specifically, this software could be used to prioritize pavement marking decisions. It could be used to compare the importance of wet-night needs to daytime and dry conditions. Pavement marking needs could be compared by their relative importance to other safety features and asset groups. In summary, the Decision Lens software offers an opportunity to solicit input from many technical experts to make collective decisions on the importance of allocating funding, where and when to place materials, and policy decisions.

### 3.3.3 UDOT Maintenance Division – Procurement vs. Construction Practices

UDOT's Maintenance Division was interviewed to identify pavement marking concerns from an operational perspective. It was quickly realized that the quantities and budgets to maintain pavement markings typically exceed those for new construction projects. Simply put, “whatever is built, must be maintained”.

While similar, the decision strategies, specifications, procurement methods, and quality control are significantly different between new construction and operational maintenance. Key among these differences is that for new construction, marking decisions are made by roadway designers and placed by private contractors. In contrast, the majority of maintenance markings are selected by maintenance engineers and placed by State crews.

This creates two sets of specifications, one for construction and another for procurement of materials. Project specifications typically have a greater oversight in the quality control for the installation process. Surface preparation techniques are often different. In addition, the selection of pavement marking materials may be left to contractors in alternative delivery (design-build) projects. For example, a construction project may require grooving of the pavement surface to inlay (recess) the material, and UDOT crews seldom place preformed tape. Another key difference is that the high cost of equipment requires State crews to make long term decisions on the types of materials they place. Finally, the effectiveness of the installed materials is highly dependent on the skill of the labor and quality of installation.

As a result, UDOT's pavement marking decision matrix should take into consideration the differences of pavement marking strategies and materials between construction projects and operational maintenance. To be effective, material and product strategies used in design must be

compatible with the resources and capabilities of state crews who maintain them. Considerations for equipment, training, level of effort to install, procurement specifications and other factors should be included in developing a new guideline.

### **3.4 Task 3: Identify Other Agency Practices**

This task included the gathering of information from other governmental agencies to identify new opportunities to improve UDOT's current Pavement Marking Selection Guide. In particular, State web pages were searched for policies, standards and guidelines. This was followed up with a short survey to identify any current efforts or feedback from State experts. The following presents an overview of the process to gather information as well as a summary of key findings that may offer value in Utah's efforts.

#### 3.4.1 Web Search of State DOT Standards, Practices and Policies

A search was conducted of State DOT web pages. The search primarily focused on looking for any policies, guidelines, and/or specifications from other State DOT's that are specifically used to select different pavement marking products under varied conditions, including wet-night conditions. In particular, our search looked to see if other states have a "pavement marking selection guide or policy", and if so does it include guidance for wet-night conditions.

A list of the findings by state is included in Appendix C. One limitation of the web search is that each state may or may not post pavement marking guidelines on their respective web pages. As a result, some states having guidelines may have been missed in this task.

#### 3.4.2 Questionnaire of State Agency Practices

In addition to the web page search of State DOT's, a follow up survey was distributed to transportation experts from State DOT's. The survey was intended to supplement the web search to identify States having Pavement Marking Selection Guidelines, any active research, and innovative strategies. The survey was not designed to provide a statistical analysis of data, but rather to gather general trends relating to the use of pavement marking products.

The following are a few highlights from the survey:

- 21 responses were received from the 50 States (42%)
- 14 of the 21 respondents (67%) represented Traffic and Safety Divisions
- 10 of the respondents reported having some form of a pavement marking guideline.
- The most consistently used materials are: water based, epoxy, Preformed Tape, and Thermoplastics.
- The least used (2 of 21 respondents) materials were methyl-methacrylates.
- 7 of 21 indicated using specialty bead materials to improve wet-night visibility.
- Manufactured Reflector Marking Products are commonly used in Non-Snow Climates and States for roadway delineation, and also used for non-traffic (curbs, barriers, islands) for snow states.
- Raised plowable markings are used on a very limited basis in winter climates.
- 7 of 21 respondents indicated considering overhead lighting with marking visibility.
- 13 of 21 (62%) respondents use “inlaid” or groove recessed installation of markings.
- 19 of 21 (90%) respondents use private contractors to place marking with new construction.
- 16 of 21 (76%) respondents use agency crews to place their maintenance markings.
- 5 of 21 (24%) respondents use warranty specifications.

### **3.5 Task 4: Literature Search – Past Research Studies**

The study included a literature search to identify formal research and development studies relating to wet-night pavement marking visibility. Web searches and informal phone calls were used to identify past research reports that may offer key information. From this, 34 formal reports were found that offered relevant and related information (see Appendix D):

### **3.6 Task 5: Identify Emerging Technologies**

This study continued with a search for emerging technologies relating to pavement markings and delineation. This included web searches of pavement marking suppliers and possible test sections. Sources of information include supplier web pages, governmental agency research and literature searches. Some of the innovative technologies identified are as follows:

- LED – Light Emitting Diode Markings
- All Weather Bead Technologies
- Recessed, Profiled and other Surface Enhancements
- Reflective Markers (Reflectors)
- Autonomous Vehicles – Using Pavement Marking Guidance

### **3.7 Summary:**

In summary, the data collection identified several sources of existing and readily available information from UDOT, other governmental agencies, and academic researchers. This information can be used to assist UDOT in comparing its current practices to the “best practices” of others. This creates an opportunity for UDOT to consider other factors, needs, processes and methods when updating its current pavement marking matrix or creating a supplemental guideline.

## **4.0 DATA EVALUATION**

### **4.1 Overview**

The data collected during Tasks 1 through 5 provided valuable information relating to the current practices for pavement markings in comparison to approaches used by other agencies. It offers a broad overview of the “best practices” being used to address decisions for wet weather and nighttime visibility of pavement markings.

This is an “applied research” study with a goal of gathering general information relating to how UDOT’s pavement marking practices compare to other governmental agencies. The results will be used to assist UDOT in reviewing and updating its current pavement marking decision matrix to include other factors such as wet-night conditions.

As a result the evaluation of the data provides a summary of general trends, practices, active research, and emerging technologies that are relevant in the selection and maintenance of pavement markings. Results are presented in qualitative terms.

## 4.2 Findings from the Review of UDOT Current Practices

An initial review of UDOT current practices was conducted with the following observations:

### 4.2.1 UDOT Current Pavement Marking Decision Matrix

UDOT current Pavement Marking Decision Matrix was reviewed. It has been in place for approximately 10 years, with periodic revisions. UDOT's current matrix is a guide to assist in the selection of materials and products. It is NOT a standard. The current decision matrix is a simple two page document that recommends different materials based on pavement type and traffic volumes. It is based primarily on durability and cost, matching materials to pavement type and traffic volumes. However, it is limited in that it does not include other factors such as crashes by location or wet-night conditions. In addition, the current decision matrix does not have any write ups to help explain its use.

*Conclusion – When updating its current pavement marking decision matrix, UDOT should consider additional factors and the creation of a guide to explain the matrix. Training should also be considered to help implement the results and use.*

### 4.2.2 UDOT Pavement Marking Committee

A review of UDOT's current practices identified that a multi-disciplined pavement marking task force has been used in the past, but is not currently being used on a regular basis. Reviews of current practices along with interviews show that pavement markings cross many technical areas. These include: Traffic, Safety, Materials, Maintenance, Design, Planning, and Research. Each of these groups often has different needs and perspectives. Collectively each of these areas could provide input to make a broader decision making strategy than working independently.

*Conclusion - UDOT could benefit by reinstating its previous Pavement Marking Committee. This would offer a multi-disciplinary approach to pavement marking strategies and decisions and improve communication between the technical groups.*

#### 4.2.3 UDOT Standard Specifications

UDOT's current practices show that there are major differences between project specifications used for construction and material procurement specifications used to maintain markings. In addition, the procurement of materials for maintenance markings must include consideration for issues such as equipment costs, training, and quality control of the installation. Products and materials selected for construction projects must be compatible with maintenance capabilities and resources. Also, it was found that there is an opportunity to expand construction specifications to include a greater emphasis on marking visibility in construction work zones.

*Conclusion – When creating construction specifications, consideration should be given to the types of materials to be used in comparison to the resources and capabilities of the crews that maintain them.*

#### 4.2.4 Use of Nu- Metrics Traffic and Safety Software to Include Safety Aspects in the Guideline

Under the direction of W. Scott Jones, PE, UDOT recently implemented the use of a new software tool (Nu-Metrics) that allow non-traffic experts to easily retrieve traffic and safety data. This information could be used to assist in selecting pavement marking materials as a tool in response to known problem areas. It could be applied to:

- Site Specific - Response to Crash Locations
- Characteristic Specific: ADT, Function Class and Traffic Classifications
- Project Scoping
- Corridor Studies and Planning
- System Wide
- Cross Asset Prioritization

## Potential Steps to Utilize Nu-Metrics Crash Data Software

### Performed and Distributed by Traffic Engineer

- 1- Identify locations on state highways that have a significantly high number of wet-weather night crashes (three-year data file).
- 2- Using this list provide tables of more detailed data related to the crashes at those sites. These would include factors such as:
  - a. Severity (1 – 5)
  - b. Crash types (run-off-the road, rear-end collisions, head-on crashes, etc.)
  - c. Contributing circumstances (alcohol/drugs, drowsy driver, speeding, etc.)
  - d. Vehicle classes (autos, heavy trucks, etc.)
  - e. Highway characteristics (AADT, functional class, number of lanes, etc.)
  - f. Pavement skid index
  - g. Pavement type (concrete, bituminous surface course, open-grade surface course)
  - h. Highway drainage characteristics (poor cross slope, rutting, etc.)
- 3- Analyze the data and determine root causes of the crashes (main cause, secondary causes)
- 4- Recommend safety improvements to the location which may include upgrades in the pavement marking materials and installation methods.

#### 4.2.5 Use of Decision Lens Software to Develop the Pavement Marking Guide

Under the direction of John Thomas, PE, UDOT recently implemented the use of a new software tool (Decision Lens) which is used to assist technical experts in prioritizing competing needs. In many ways, it is similar to a computer based “value engineering” process. The process could be used in coordination with the pavement marking task force to prioritize needs within the pavement marking selection guide as outlined in the following steps:

1. **Identify Experts:** Select a team of experts to provide oversight to the selection criteria and performance tracking of pavement markings on Utah’s state highways.
2. **Select Criteria:** Determine which factors should be used to select the appropriate pavement markings for both new and existing highways. This should include current considerations for pavement type and traffic volumes, along with additional factors such as climate, crash data, and construction work zones.
3. **Establish Appropriate Levels:** Establish and verify a set of acceptable threshold values to measure and quantify the effectiveness of pavement marking visibility. This could include variables such as retro-reflectivity, bond durability, and color stability over time.
4. **Create a Pavement Marking Guide (that includes a Selection Matrix):** Create and publish tools to aid UDOT personnel in the selection of pavement markings using the factors and levels identified in steps 2 and 3.
5. **Provide Training:** The implementation of the new pavement marking guide should include training to enhance acceptance, understanding and use.
6. **Monitor the Process:** Establish methods to monitor performance of the selected pavement markings. This should include information on how they performed over time, and track the life cycle cost for each pavement marking system.
7. **Policy:** Determine if any of the decision strategies or methods to select should be formal policies rather than guides.

Conclusion – There is an opportunity for UDOT to use recently developed software systems existing within the Department to assist in the review and updating of the pavement marking decision matrix. In particular, these include NuMetrics, and Decision Lens software.

### **4.3 Findings from Other State (Agency) Practices**

Web pages search of State DOT's were reviewed to identify any relevant information relating to pavement marking selections and decisions, including wet-night conditions. Because web pages tend to provide broader organization information, a follow up survey was also distributed to look for the same information. The following information was gathered through the web page searches and survey that may be beneficial in UDOT's goal to improve its pavement marking selection guide:

#### 4.3.1 Multi-Disciplined Approach to Pavement Marking Decisions

A key observation from the reviews of other state practices was the uncertainty of who is the best person or technical area to discuss pavement marking issues and decisions. This was also an observation when interviewing UDOT professionals. Pavement markings, and other traffic/safety features typically are influenced by several technical areas including, planning, design, construction, asset management, materials, research, traffic and safety.

In general, many of the States that showed greater organization and documentation of processes, guidelines and innovative research, were also those with formal task forces or working groups comprised of different technical areas. These groups in other states were typically a Pavement Marking Committee or a broader Traffic and Safety Products Committee. It is felt that the improved communication helps to improve communication and consensus, while also avoiding a duplication of efforts.

Conclusion – This observation supports the previous conclusion that it would be beneficial for UDOT to reintroduce a pavement marking or traffic and safety committee.

### 4.3.2 States with Expanded (Multi-Factor) Pavement Marking Selection Guidelines

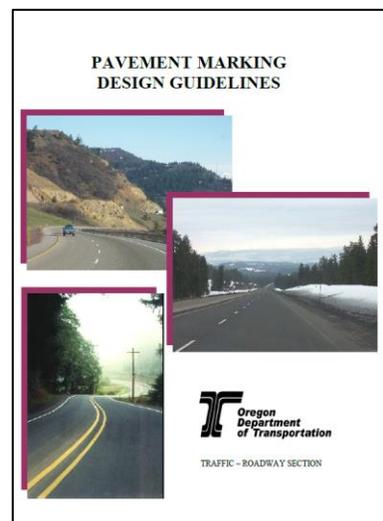
The results of the other agency search (web and survey) found that the majority of State DOT's do not have a guide or policy that is specifically for selecting different pavement marking materials or products.

Most of the States that do have some form of a guideline for pavement markings, includes basic information of how designers should use the materials or products to comply with the Manual of Uniform Traffic Control Devices (MUTCD), local preference, geometric conditions and other design factors.

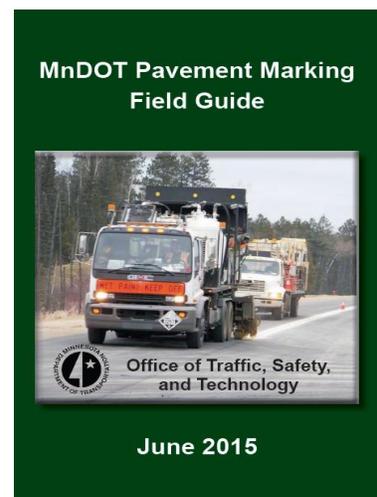
Of the States that did have a Pavement Marking Selection Guide, the products or materials were identified based primarily on traffic volumes and pavement type (similar to UDOT). In addition, pavement marking selection guidelines were typically part of a broader chapter on Pavement Markings and/or part of a Traffic and Safety Guideline or Manual.

However, at least three states (California, Oregon, and Minnesota) were found to have broader based pavement marking selection guides that consider additional factors such as safety and climate conditions. These other state practices offer potential opportunities for consideration as UDOT reviews its current selection guide.

In addition, while UDOT has an established pavement marking selection guide, it is limited to a two page working chart. In comparison, several other states have formal written documented guidelines that offer additional explanation and guidance to support the technical understanding of a selection matrix.



**Figure 2 – Oregon Guide**



**Figure 3 – MnDOT Guide**

Conclusion - There is an opportunity for UDOT to build upon the efforts of other State DOT's in reviewing and updating its pavement marking selection guide. In particular, other factors should be considered such as climate conditions, crash data, roadway geometrics, climate conditions, and construction work zones. UDOT should consider including pavement marking guidelines as a part of a larger Traffic and Safety Manual.

#### 4.3.3 Relative Importance of Wet-Night Conditions

Other governmental agencies were asked to rate the importance of pavement marking visibility under wet-night conditions in comparison to other conditions, such as dry-daytime. Surprisingly, 11 of the 19 respondents (58%) stated that it was not more important, or only slightly more important.

It is speculated from some responses to other questions, that engineers are concerned with a variety of conditions that require good pavement marking visibility. These include: dry-night visibility, daytime color contrast, and overall durability of marking materials. Respondents also expressed that one of the concerns for wet-night visibility is the markings wearing out during a winter season when they can't be refreshed.

In addition, many of the warmer states (limited winter condition) did not rate wet-night visibility as high of a concern. It is speculated that this may be due to the ability to use surface mounted reflectors that offer better reflectivity than bead technology.

Finally, Utah is one of the driest states in the nation, with far less rainy days/nights than other states. As a result, the justification to spend additional funds on wet-night markings at the expense of other risk mitigation may not be warranted. Many states responded that visibility under wet night conditions, is not a significantly greater concern than other nighttime and climate conditions. Many of these were warmer climates with limited snow removal, and the use of raised reflectors. In addition, states with winter snow removal look for durable markings that can last an entire winter season. Daytime contrast and color stability under high UV conditions are also concerns to some locations.

Conclusion - The need for improved wet-night pavement marking products is highly dependent on the location and climate conditions. There is an opportunity to look at crash data to help identify problem areas (hot-spots).

#### 4.3.4 Installation Practices (Inlaid)

Over half of the states reported that they use installation practices to recess (grooved or inlaid) pavement marking materials as a method to successfully extend durability (and indirectly visibility). Utah has approved the use of pavement recessed (grooved) installation practices. They have also experimented with the use of recessed reflectors (scalped into pavement). However, there appears to be uncertainty on where and when these installation practices should be considered as part of the overall marking selection guide.



**Figure 4 – Scallop Recessed Reflective Marker**

Conclusion - UDOT's current pavement marking standard drawings, specifications and decision matrix should be reviewed and updated to provide greater clarity on when and where pavement grooving should or shouldn't be used.

#### 4.3.5 Additional Factors Influencing Pavement Marking Decisions

The majority of state and local agencies selecting pavement markings based on a comparison of durability and cost, comparing the product to traffic volumes and pavement type (wear factors). However, the survey shows that many of the respondents listed other factors that should be considered when choosing a pavement marking material. These include:

- Crash History, Locations and Severity
- Roadway Geometrics (lanes, interchanges, grades, curves, shoulder widths, etc.)
- Functional Class, separated or multi directional traffic.
- Cross walks, pedestrian, and cyclist use.
- Climate conditions (wet weather, winter weather, plowing practices, UV).
- Construction Work Zones

Conclusion - UDOT could benefit by considering additional factors when updating its current pavement marking decision matrix and/or creating a pavement marking guideline. These factors include crashes, climate, location, and roadway characteristics.

#### 4.3.6 Emerging Technologies and Practices to Improve Wet-Night Visibility

Governmental agencies were solicited to see if they have any unique or innovative products, materials, or practices that they use to improve wet-night visibility. The responses did not identify any new processes, but did confirm current efforts being used or introduced by UDOT. The most common approaches to improving wet-night visibility primarily focused on either recessing the markings to extend life (durability) or increasing the profile of the beads or markings to drain water. Common approaches used included:

- Recessed Markings and Reflectors
- Wet Reflective Bead Products
- Epoxy and Tape Products
- Open graded pavements to improve drainage
- LED – Light Emitting Diode Technologies

Conclusion - The survey of other agencies supports UDOT's current efforts and awareness of emerging technologies to address wet-night and overall pavement marking visibility. In particular, these approaches tend to be based on extending the durability or increasing the surface profile to improve drainage. UDOT should consider additional test sections to evaluate emerging products and technologies.

#### 4.3.7 Construction Work Zones

Construction work zones have historically shown to have higher than average accident rates. Narrow lanes, driver confusion, congestion, speed differentials, lane shifts and geometrics are considered contributing factors. In these conditions, pavement markings play a significant role in communication with the driver. One of the questions asked of governmental agencies was if they used any special products or strategies for construction work zones. Several expressing having work zone marking standards and the use of innovative products. Some of the innovative approaches used in construction work zones include: [19,23]

- Removable Pavement Marking Tape.
- Experimental Fluorescent Orange Paint Lines.
- Sacrificial Raised Reflective Markers.
- New Wet Reflective Standards in Work Zones.

Conclusion - A review of the current pavement marking selection guide should consider the needs of construction work zones, along with additional research and test sections specific to work zones.

#### 4.3.8 Construction vs. Maintenance (Procurement) Specifications

Utah commonly installs pavement markings for new construction with private contractors, and in-house crews for maintenance. The search of other state practices shows this is a very common approach. However, the specifications for construction are often different than those for the purchase of materials (procurement). This potentially can lead to different specification requirements depending on who places the material. In addition, the ability for either state crews or private contractors to install pavement markings requires long-term commitments for expensive equipment and training of personnel. Any strategies regarding what materials to use must include consideration for both the long-term investment in both equipment and trained labor.

Conclusion - Any guidelines for the selection of pavement marking materials should take into consideration the long-term capital investment required for equipment, who is best to place the materials, and qualifications of installers. There is an opportunity to create specifications for new construction that are similar in scope to those for procurement.

#### 4.3.9 States with Active Research and Test Sections

Several governmental agencies expressed active research or test sections for pavement markings. Many of these are aimed at improving nighttime visibility (dry or wet). Others include field testing and evaluation of emerging technologies. Some of the key state efforts to follow include:

- FHWA Pooled-Fund Study – completed in October 2015
- Wisconsin DOT – Current efforts to update a Pavement Marking Guide
- Washington DOT - Test Sections/Research into the use of LED marking systems.
- Michigan DOT – Development of Pavement Marking Performance Measures
- Minnesota DOT – Evaluation of Specialty Bead Products for Wet Weather
- Colorado DOT – Test Sections for Recessed Markings (grooving)
- Virginia DOT – All Weather Marking Research
- TTI – Research Organization with several Marking Studies
- Arizona DOT - Profiled Thermoplastics, Rumble Strips, Recessed Markings.

Conclusion - UDOT should continue to follow the progress of ongoing research by other state DOTs and agencies for potential implementation. Specifically, there is an opportunity for UDOT to participate in pooled-fund studies, scanning tours, use data from these other studies, and/or independently conduct research or test sections.

#### 4.4 Findings from the Literature Search – Past Research Studies

The study included a literature search to identify formal research and development studies relating to wet-night pavement marking visibility. Web searches and informal phone calls were used to identify past research reports. These past research reports provided valuable information regarding factors influencing wet-night pavement marking visibility, safety issues and benefits, durability, drainage issues, and recessed systems to improve visibility.

##### 4.4.1 Factors (Issues) Influencing Wet-Night Marking Visibility

Past research studies and reports provided a general and consistent list of challenges that influence the visibility of pavement marking products under wet-night conditions. The past research studies and reports provided a general and consistent list of challenges that influence the visibility of pavement marking products under wet-night conditions. These include:

[1,2,3,5,13,17,18,23,24,25,28,29]

- Type of material and installation methods.
- Economic decisions (service life and durability versus the cost of the materials).
- Early wear and damage to materials by forces such as weather and traffic wear.
- Ongoing need to develop strategies and tools to measure retro-reflectivity.
- Installation and maintenance issues including shortages of skilled workers.
- Location of installation, climate and traffic load on roadway.
- Funding and standards for maintenance.
- New technologies continuously entering the market, each requiring evaluation.
- Environmental regulations.
- Product acceptance and approval processes.
- Driver needs (including differing needs based on driver age and time of day).
- Vehicle type and the visibility concerns of trucks vs. cars

Conclusion - Research studies show that there are numerous factors that should be considered when selecting a pavement marking material or product, including: location, climate, crash data, surface drainage and roadway characteristics.

#### 4.4.2 Safety Benefits Related to Wet-Reflective Pavement Marking Visibility

One of the more significant findings of the literature search is a pooled-fund study that was recently completed for the FHWA involving 38 states. The study provides insight on the use and effectiveness of wet-night pavement marking products in reducing the quantity or severity of crashes. The study quantified the effectiveness with a benefit to cost approach. Data was collected from three States: Minnesota, North Carolina and Wisconsin who participated in the study. [14,17,24,26,34]

**Table 1 Crash Reduction Modification Factors FHWA Pooled-Fund Project [34]**

<b>Highway Systems</b>	<b>Crash Types*</b>	<b>Crash Modification Factors**</b>	<b>Benefit-Cost Ratio*** (Range)</b>
➤ Freeway	<ul style="list-style-type: none"> <li>• Wet-road crashes</li> <li>• Injury crashes</li> </ul>	<ul style="list-style-type: none"> <li>• 0.861</li> <li>• 0.881</li> </ul>	<b>1.45</b> <b>(0.83 to 2.04)</b>
➤ Multi-lane	<ul style="list-style-type: none"> <li>• Wet-road crashes</li> <li>• Night-time crashes</li> <li>• Total crashes</li> <li>• Injury crashes</li> <li>• Run-off-road crashes</li> </ul>	<ul style="list-style-type: none"> <li>• 0.751</li> <li>• 0.696</li> <li>• 0.825</li> <li>• 0.595</li> <li>• 0.538</li> </ul>	<b>5.44</b> <b>(3.10 to 7.67)</b>
➤ Two-lane	<ul style="list-style-type: none"> <li>• Wet-road crashes</li> <li>• Total crashes</li> </ul>	<ul style="list-style-type: none"> <li>• Indicated, but small sample size</li> <li>• Indicated, but small sample size</li> </ul>	

\*Crash category omitted: snow & ice, intersection, and animal related.

\*\*Significant at 0.95 confidence level.

\*\*\* All Crash Types

The FHWA pooled-fund study further evaluated the crash reduction for different roadway characteristics, and types of crashes. Crash data from three states were used in the research. . This study confirms earlier information gathered that accident hot-spots and the

benefit of wet-night reflective pavement markings is typically at multi-lane highways with wet climates. The correlations found in the study are shown in Table 4.1 above.

Another study performed in Alberta, Canada reported that wet-night high visibility pavement markings reduced collision costs by 2.5%. Highways with higher traffic volumes typically have higher total numbers of crashes. Therefore, this study shows that highways with higher volumes or total numbers of accidents per mile are most beneficial for effective pavement markings and all traffic and safety features.

Conclusion - When properly selected, installed, and effectively maintained, retroreflective pavement markings can significantly improve a driver's ability to navigate in wet-night conditions, with the potential to decrease crashes and severity. This is especially beneficial in high volume, multi-lane systems, with known wet weather climates.

#### 4.4.3 Research Related to the DURABILITY of Pavement Marking Systems

A key finding of the literature search was research that suggests pavement markings often wear out prematurely (low durability), especially during the winter months when they can't be reapplied. This is often attributed to plowing operations. At the same time, these winter months also have the longest nighttime hours and often are the wettest months. During the winter months temperatures often prohibit replacement of the markings. [1,8,12,24,25,32,33]

As a result, the research suggests that designers should not simply look at which materials last the longest, but rather match product life cycles to last a full winter season. For less durable products such as water-based paints, this means finding paints, beads, and installation methods that will extend the life to last a full winter season.

Another research report (Migletz 2002), supports the experiences of drivers having difficulty seeing the road when pavement markings fail or their reflectivity is reduced, and the need to consider durability in the selection of pavement marking products. In another finding, a pooled-fund research was performed with input from several State DOT's and organizations relating to the durability or service-life of pavement markers and markings. Their work can be

found in section I: “Durability of Retroreflective Pavement Markings, Markers” (24) with participation from the following:

- Texas Transportation Institute (TTI)
- Virginia Transportation Research Council (VTRC)
- Federal Highway Administration (FHWA)
- New Jersey DOT
- Alabama
- Oregon DOT
- Florida DOT
- Georgia DOT
- Indiana DOT
- American Society of Civil Engineers
- ARRB Group Ltd.

Conclusion - Research suggests that decision-makers should not only consider a comparison of durability to cost (value), but also consider the durability and installation times of materials and products that can last a full winter season. In particular, the past research shows that preformed tapes, epoxies and thermoplastics, tend to last longer. It also suggests that new bead technologies combined with grooving (inlaid) or other installation practices increase the visible life of most products.

#### 4.4.4 Current Research Targeted Specifically for Wet-Night Visibility

The vast majority of past research relating to wet-night pavement marking visibility was performed directly by governmental agencies or by academic institutions on behalf of the governmental agencies. These other agency research studies provide an opportunity for UDOT to cost effectively build upon past efforts, and focus its research on specific areas. It also suggests that there is a significant benefit of UDOT engineers to communicate and collaborate with other agencies, including participation on national committees, scanning tours, and pooled-fund studies.

The following governmental agencies or organizations were a few of those having current or proposed research relating specifically towards the retro-reflectivity during wet- nighttime driving conditions. Additional information and contacts can be found in the Appendix.

- Oregon State University
- Iowa State University
- Mississippi State University
- North Dakota DOT
- Pennsylvania DOT
- FHWA – Study name - Contact
- Virginia DOT – Study Name
- Texas DOT – Study Name - Contact
- Alaska DOT – Study Name and Contact
- Minnesota DOT

Conclusion - The literature search suggests that active research is underway specifically targeted towards wet-nighttime visibility. There is an opportunity for UDOT to efficiently follow the progress of these studies for potential implementation of new findings. Scanning tours of test sections, participation in pooled-fund studies, and national committees offer good method to do share resources and communicate results.

#### 4.4.5 Drainage Issues Related to Wet-Reflective Pavement Marking Visibility

Standing water on the pavement surfaces reduces retroreflectivity, causes glare from on-coming traffic, can result in vehicle hydroplaning, reduces resistance to skidding, and produces tire spray. The literature search identified several state agencies who reported that the use of Open-Graded Surface Courses (OGSC) improved drainage away from pavement markings and reduced spray. These aspects can have a significant impact on visibility during wet-night driving conditions. UDOT has utilized OGSCs for many years and have observed positive safety impacts from their use. In addition, Utah and other states have experimented with the use of recessed reflectors (scalloped pavement), and painting of rumble strips (surface profiling) as tools to improve wet reflectivity. These techniques appear to be viable tools to address problem areas such as multi-lane, high ADT, wet climate locations, poor geometrics, or high crash areas.

Conclusion - Research suggests there is an opportunity for UDOT to consider additional pavement types such as OGSC, Chip Seals, and Rumble Strips as a tools to improve wet-night marking visibility in locations where high precipitation is likely.

#### 4.4.6 Recessed Systems to Improve Wet-Reflective Pavement Marking Durability

Several research studies referred to state agencies using a practice of recessed pavement markings, where the pavement surface is grooved prior to installation. The studies suggest that this installation method has a significant benefit in extending the retroreflective life of the markings, especially in locations that receive winter plowing operations. This is largely attributed to the prevention of the beads being sheared off by plows. [1,5,6,13,14,16,17,21,24]



**Figure 5 – Recessed Pavement Marking Tape**



**Figure 6 – Grooved Pavement Surface**

Conclusion - Research shows that many State DOT's are successfully using an installation practice of recessing (pavement grooving) of pavement markings to extend the durable life of the marking, with significant benefits in areas with high plow activities.

## 4.5 Emerging Technologies Identified

This study continued with a search of emerging technologies relating to pavement markings and delineation. This included web searches of pavement marking suppliers and possible test sections. Sources of information are supplier web pages, governmental agency research and literature searches. Some of the innovative technologies identified are as follows:

### 4.5.1 LED – Light Emitting Diode Markings

LED technology has improved dramatically over the past 3-4 years with increased brightness and lower energy consumption. Several companies have developed flush mounted LED “pucks” that are recessed into the pavement and plowable. This is a dramatically new approach to pavement in that it provides a light source rather than relying on “retro-reflectivity”.

Several State DOTs are actively exploring the use of Light Emitting Diode Technology. In particular, the State of Washington has an active test section at Snoqualmie Pass which receives significant snow during the winter. In addition, the United Kingdom is widely accepting the use of LED technology for both pavement markings and overhead roadway lighting.



Figure 7 – Snowqualmie Pass LED Test Section



Figure 8 – Snoqualmie LED Marker



Figure 9 – Other LED Marker Types

#### 4.5.2 All Weather Bead Technologies

Several State DOTs indicated that they are experimenting with the use of advance bead technologies to improve wet-night visibility. There are several companies who supply beads and have web sites promoting these new products. The new bead technologies appear to improve the reflectivity, but the durability under snow plowing conditions remains uncertain. New bead technology is an opportunity for UDOT to follow. [2,3,6,13,23,24,25,27]

- Large Beads
- Cluster Beads
- Size Distribution
- Dual Optic Elements
- High Index Beads

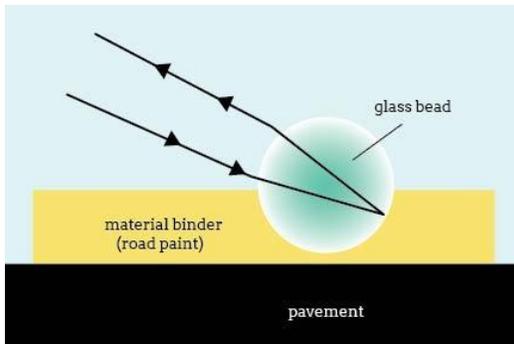


Figure 8 – Dry Retro-reflectivity

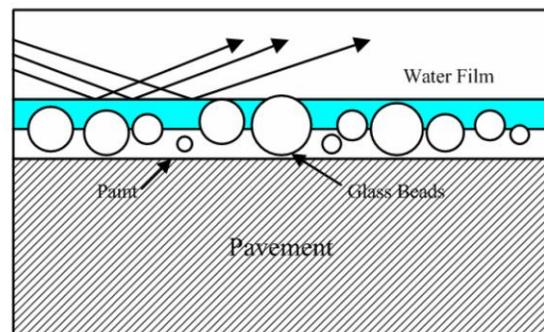


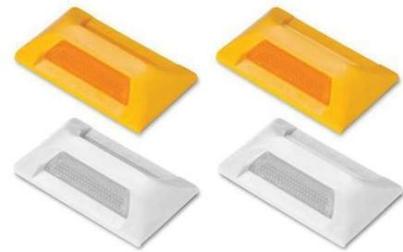
Figure 9 – Wet Diffused Reflectivity

#### 4.5.3 Recessed, Profiled and other Surface Enhancements

UDOT and many other states are experimenting with the grooving of the pavement surface to recess pavement markings. The benefit of this is the increased durability of the reflective beads, especially in snow removal areas. However, UDOT currently does not have a guide or policy on when and where to use recessed markings.

#### 4.5.4 Raised Reflective Markers (Reflectors)

Many warmer states are successfully using surface mounted Pavement Marking Reflectors. These reflectors do not work well in winter plowing areas. Utah is successfully using reflectors on islands, curbs and barriers. However, there may be opportunities to use these products in other non-plowable areas. Also, several states have successfully used a “scalloped groove” to recess the reflectors, which may be a consideration for Utah in problematic locations.



**Figure 10 – Example Raised Reflective Marker**

Conclusion: The research study identified several emerging technologies that should be considered for further research, evaluation, test sections and potential use. Among these are LED Pavement Marking Lighting, All Weather Materials (beads and substrate), and Surface Profile Enhancements.

## **5.0 SUMMARY OF CONCLUSIONS**

This study included a review of UDOT's current pavement marking selection guide, standards and processes. Information was also gathered from other State DOT's and a Literature Search of past research. UDOT's current practices were then compared to the "best practices" of these other agencies. The goal of the study is to look for opportunities for UDOT to consider updating its current pavement marking decision matrix, including concerns for wet-night visibility.

Several conclusions were generated from the data collection and evaluation process. Collectively this information offers several potential opportunities for UDOT to consider in its efforts to review and revise its current guide. A Summary of Conclusions include the following:

1. The reintroduction of a Pavement Marking and/or Traffic & Safety Committee would be beneficial in making strategy decisions, effective communication and coordination between technical groups.
2. UDOT's current Pavement Marking Decision Matrix is working well to select materials and products based on durability and cost. However, there is a significant opportunity to expand the matrix to include consideration for other factors such as known crash locations, climate specific locations, and construction work zones.
3. There is an opportunity to create a Pavement Marking Guide that supports and helps to explain the decision matrix. This guide should also be considered as a chapter in a larger traffic and safety manual
4. Review current standard drawings, specifications and decision matrix to provide greater clarity on when and where to use inlaid (pavement grooving) practices.
5. The use of UDOT's current Decision Lens Software could be used in helping to develop decision strategies for the selection of different pavement marking materials under different conditions. The software could also be used as a tool to consider Wet-Night condition in comparison to other risk factors.
6. The use of UDOT's current Nu- Metrics Traffic and Safety Software could be used to

consider additional crash data, in comparison to location, climate conditions, roadway geometrics, and other factors. This analysis could be used to assist in selecting pavement markings for hot-spots, specific locations, individual projects, corridor studies or a system wide basis.

7. There is an opportunity for UDOT to efficiently build upon the work of other agencies through scanning tours, participation on national committees and pooled-fund studies.
8. There are continuously emerging technologies that may help in improving the visibility of pavement markings under wet-night conditions. UDOT should continue to solicit input from vendors and place test sections for evaluation.

## **6.0 RECOMMENDATIONS AND IMPLEMENTATION**

Based on the information discussed in the previous sections, the following recommendations are suggested for further consideration and implementation:

### **6.1 Utilize the Pavement Marking Quality Improvement Team**

UDOT currently has a Pavement Marking Improvement Team. There are many experts within UDOT having a technical interest in pavement markings and delineation. These include designers, construction, asset management, traffic and safety, maintenance, and materials professionals. The effective support of this task force is critical to developing a multi-disciplined approach to pavement marking issues. The support of this task force should be revisited to ensure that it is fully supported to help with reviewing strategies, selecting new research, test sections, and specification recommendations.

### **6.2 Create a Formal Pavement Marking Guide Document**

UDOT currently has an established pavement marking selection guide. However, it is limited to a two page working chart. In comparison, many states have formal written documented guides that offer explanation and guidance to support technical understanding. A Pavement marking guide could include additional factors and assist designers, planners, maintenance and others in selecting pavement marking materials. It should remain as a “guide” and not as a standard or specification. This guide should also be supplemented with training sessions to explain the importance and use of the guideline.

### **6.3 Include Additional Factors to Selection of Markings**

UDOT currently has a pavement marking guide that is primarily based on matching marking products to differences in traffic volumes and pavement type. The current approach uses a best value of durability in comparison to cost. However, there are limitations in that it does not adequately address considerations for other factors such as known crash locations, construction work zones, climate conditions, etc. There is an opportunity for UDOT to expand its current guideline to include a 2nd tier for these “other factors”. Some of the additional factors to consider include:

- Selection based in response to known crashes, injuries, and fatality locations
- Roadway Geometrics (horizontal curves, steep grades, substandard shoulders, etc.)
- Traffic - Urban, high volume, high movement, fluctuations, etc.
- Pedestrian Crossings and Bike Paths
- Climate Conditions such as High Snow, Wet Weather, UV exposure, etc.
- Construction Work Zone Markings
- Driver Behavior (cell phone, impaired, elderly, etc.)

#### 6.4 Clarify When and Where to Use Inlaid (Groove Recessed) Installation Practices

Because of Utah's climate and snow removal efforts, the durability and reflective properties rapidly deteriorate from abrasion from plows, tires, and deicing materials. The research confirms UDOT's recent efforts to use inlaid (groove recessed) pavement markings. With this approach, the pavement is grooved to recess the markings below the surface. UDOT currently includes references to the use of pavement grooving in their standard drawings and specifications. However, greater clarity could be given in the pavement marking decision matrix on when and where to use this installation practice.

#### 6.5 Evaluation of Emerging Technologies

It is recommended for UDOT take a proactive approach to further explore promising opportunities from the use of new technologies. Specifically, the following technologies should be considered for further research and/or test sections:

- LED – Light Emitting Diode Pavement Delineation
- Enhanced Bead Technologies for Wet Night Conditions
- Grooved (inlaid) pavements to recess markings
- Striping of Rumble Strips
- Profile Thermoplastics
- Reflective Markers for Islands, Curbs and Barriers.
- Grooved or Recessed Reflective Markers.

The evaluation of new technologies should consider factors such as cost, durability, safety benefits, installation and operational aspects. Outreach to vendors, scanning tours and test sections are recommended.

## 6.6 Use of Decision Lens Software to Assist in Decision Guide

It is recommended for UDOT to expand the consideration and inclusion of its broader strategic goals of Safety, Mobility and Preservation into the selection of pavement marking materials. A key tool that is further recommended is the use of new software (Decision Lens) that is being used as strategic tool within UDOT's Planning Division. This software offers a "qualitative" approach to the decision process.

## 6.7 Use of Nu-Metrics Software to Include Traffic and Safety Aspects

It is recommended for UDOT to evaluate the use of a new software tool (Nu-Metrics) that is being used by its Traffic and Safety Division to provide a quantitative approach to traffic and safety hot spots. This software could be used for both the design (project) and operational (maintenance) selection of pavement markings, signing, etc. to give a comprehensive approach.

## 6.8 Training to Support Guide Implementation and Quality Practices

The effectiveness of the acceptance and use of a pavement marking guide can be greatly improved through training. In addition, the quality and durability of pavement marking materials can be enhanced with a formal training initiative.

## 6.9 Peer Exchange

There is an opportunity for UDOT to continue to share information and coordinate efforts with other governmental agencies, academia, and suppliers. The use of pooled-fund studies, scanning tours, and participation in technical organizations is highly effective.

## APPENDIX A: UDOT RESEARCH PROBLEM STATEMENT

<b>2015 UDOT RESEARCH PROBLEM STATEMENT</b>			
<i>*** Problem statement deadline is <u>March 10, 2015</u>. Submit statements to Jason Richins at <a href="mailto:jrichins@utah.gov">jrichins@utah.gov</a>. ***</i>			
<b>Title:</b> Plowable Pavement Markings under Wet-night Road Conditions		<b>No. (office use):</b> 15.02.01	
<b>Submitted By:</b> Ken Berg		<b>Organization:</b> Maintenance Planning	
<b>Email:</b> kenberg@utah.gov		<b>Phone:</b> 801 965 4321	
<b>UDOT Champion (suggested):</b> Ken Berg			
<b>Select a Subject Area</b>	<input type="checkbox"/> Materials/Pavements	<input checked="" type="checkbox"/> Maintenance	<input type="checkbox"/> Traffic Mgmt/Safety
	<input type="checkbox"/> Preconstruction	<input type="checkbox"/> Planning	<input type="checkbox"/> Structures/Geotechnical
<p><b>1. Describe the problem to be addressed.</b>                      Pavement striping visibility in wet conditions has always been a problem for motorists. The problem is much worse at night, when water film on the pavement surface reflects light in random directions rather than back to the driver. Winter maintenance practices often limit the thickness of pavement markings or devices above the road surface. This creates a very difficult time for all motorists, and particularly older drivers, to see pavement markings under wet-night road conditions. A variety of pavement marking visibility strategies are extant, including lighting, pavement markers, retroreflective bead, high durability permanent pavement markings, and various paint application strategies.</p>			
<p><b>2. Explain why this research is important.</b>                      Improving visibility of pavement markings will increase safety.</p>			
<p><b>3. List the research objective(s):</b></p> <ol style="list-style-type: none"> <li>1. Identify best practices for wet-night visibility including rain, mist/fog, and winter plowing conditions</li> <li>2. Identify effective wet-night visibility systems, devices, and products and conditions where they work best.</li> <li>3. Identify promising emerging wet-night visibility technologies</li> <li>4. Recommend further research, development, or field testing to advance the science of wet-night visibility</li> </ol>			
<p><b>4. List the major tasks:</b></p> <ol style="list-style-type: none"> <li>1. Comprehensive literature search, including non-US research and practice, both from highway and other transportation industries.</li> <li>2. Prepare a list of products and devices available to implement various plowable wet-night visibility strategies</li> <li>3. Create wet-night pavement visibility selection matrix for traffic conditions, weather condition, durability, and relative life-cycle expense</li> <li>4. Prepare recommendations for further research, development or field test deck demonstration.</li> </ol>			
<p><b>5. List the expected results:</b></p> <ol style="list-style-type: none"> <li>1. Final report that includes the accomplishments of the above tasks.</li> </ol>			
<p><b>6. Describe how this research will be implemented.</b>                      The information and recommendations of this research could be implemented by transportation agencies at all levels who have wet-night pavement marking visibility issues. Specific problem areas could be identified and an appropriate strategy selected to improve user safety. The recommendations may also be used as a guide for avoiding wet-night visibility issues with new construction and rehabilitation projects. Those responsible for long-term maintenance of transportation facilities could use the matrix as a selection tool</p>			

**Page 2**

for asset management tradeoff analyses.

**7. Requested from UDOT:** \$20000

**Other/Matching Funds:** \$

**Total Cost:** \$

**8. Outline the proposed schedule, including start and major event dates.**

Oct 2015 – Publish RFP

Jan 2016 – Award research contract

Feb 2016 – Literature search complete

Mar 2016 – Submit draft final report for review

1 June 2016 – Submit final report

## APPENDIX B: PAVEMENT MARKING DECISION MATRIX

**PAVEMENT MARKING DECISION MATRIX<sup>A,B,3</sup>**  
Rev. Feb. 4, 2013

SURFACE TYPE	TIME TO NEXT TREATMENT <sup>D</sup>	AADT			REMOVAL RECOMMENDATION
		Low <15,000	Medium 15,000-50,000	High >50,000	
Concrete	Greater than 5 years	tape <sup>2</sup> multiple component durables <sup>1</sup> waterborne grooving recommended <sup>C</sup>	tape <sup>2</sup> multiple component durables <sup>1</sup> waterborne grooving recommended <sup>C</sup>	tape <sup>2</sup> multiple component durables <sup>1</sup> waterborne grooving recommended <sup>C</sup>	waterblasting <sup>5</sup> sandblasting grinding <sup>4</sup>
	2 to 5 years	waterborne	waterborne	waterborne	waterblasting <sup>5</sup> sandblasting grinding <sup>4</sup>
	Less than 2 years	waterborne	waterborne	waterborne	waterblasting <sup>5</sup> sandblasting grinding <sup>4</sup>
Microsurface	Greater than 5 years	waterborne grooving recommended <sup>C</sup>	multiple component durables <sup>1</sup> waterborne grooving recommended <sup>C</sup>	multiple component durables <sup>1</sup> waterborne grooving recommended <sup>C</sup>	waterblasting <sup>5</sup> sandblasting grinding <sup>4</sup>
	2 to 5 years	waterborne	waterborne	waterborne	waterblasting <sup>5</sup> sandblasting grinding <sup>4</sup>
	Less than 2 years	waterborne	waterborne	waterborne	waterblasting <sup>5</sup> sandblasting grinding <sup>4</sup>
Open Graded Surface Course (OGSC)	Greater than 5 years	waterborne grooving recommended <sup>C</sup>	tape <sup>2</sup> multiple component durables <sup>1</sup> waterborne grooving recommended <sup>C</sup>	tape <sup>2</sup> multiple component durables <sup>1</sup> waterborne grooving recommended <sup>C</sup>	waterblasting <sup>5</sup> sandblasting grinding <sup>4</sup>
	2 to 5 years	waterborne	waterborne	waterborne	waterblasting <sup>5</sup> sandblasting grinding <sup>4</sup>
	Less than 2 years	waterborne	waterborne	waterborne	waterblasting <sup>5</sup> sandblasting grinding <sup>4</sup>
Stone Matrix Asphalt (SMA)	Greater than 5 years	waterborne grooving recommended <sup>C</sup>	tape <sup>2</sup> multiple component durables <sup>1</sup> waterborne grooving recommended <sup>C</sup>	tape <sup>2</sup> multiple component durables <sup>1</sup> waterborne grooving recommended <sup>C</sup>	waterblasting <sup>5</sup> sandblasting grinding <sup>4</sup>
	2 to 5 years	waterborne	waterborne	waterborne	waterblasting <sup>5</sup> sandblasting grinding <sup>4</sup>
	Less than 2 years	waterborne	waterborne	waterborne	waterblasting <sup>5</sup> sandblasting grinding <sup>4</sup>
Bonded Wearing Course (BWC)	Greater than 5 years	waterborne grooving recommended <sup>C</sup>	tape <sup>2</sup> multiple component durables <sup>1</sup> waterborne grooving recommended <sup>C</sup>	tape <sup>2</sup> multiple component durables <sup>1</sup> waterborne grooving recommended <sup>C</sup>	waterblasting <sup>5</sup> sandblasting grinding <sup>4</sup>
	2 to 5 years	waterborne	waterborne	waterborne	waterblasting <sup>5</sup> sandblasting grinding <sup>4</sup>
	Less than 2 years	waterborne	waterborne	waterborne	waterblasting <sup>5</sup> sandblasting grinding <sup>4</sup>
Chip Seal	Greater than 5 years	waterborne grooving recommended <sup>C</sup>	waterborne multiple component durables <sup>1</sup> grooving recommended <sup>C</sup>	waterborne multiple component durables <sup>1</sup> grooving recommended <sup>C</sup>	waterblasting <sup>5</sup> sandblasting grinding <sup>4</sup>
	2 to 5 years	waterborne	waterborne	waterborne	waterblasting <sup>5</sup> sandblasting grinding <sup>4</sup>
	Less than 2 years	waterborne	waterborne	waterborne	waterblasting <sup>5</sup> sandblasting grinding <sup>4</sup>

**General Notes:**

- A. Intended for use as a general guide and is based on performance history in Utah. Projects with special conditions may require independent decisions based on sound engineering judgement.
- B. All pavement marking and removal options are listed top to bottom in recommended selection order.
- C. Some specific recommendations for grooving are shown. In general, grooving will double pavement marking life. The decision to groove or not depends on local conditions including estimated surface life relative to estimated pavement marking life. In all cases, surface types should be sufficiently cured before they are grooved.
- D. As determined by Region Pavement Engineer

**Specific Notes :**

- 1. Referred to in the industry as "plural component durables". Permitted by Special Provision only. Manufacturer's warranty should be required.
- 2. Roadway lighting increases the visibility of tape installed in urban areas.
- 3. Consider using a durable marking if warranted by the crash data.
- 4. With approval of Resident Engineer
- 5. Use caution to avoid pavement damage.

### Pavement Marking Material Information

1/25/2010

Material	Estimated Cost per linear foot <sup>2</sup> (2009 dollars)	Actual Performance on Utah Roads <sup>1</sup>	Manufacturers Estimated Life of Product	Application Temperature	Initial Retroreflectivity (mcd/m <sup>2</sup> /lux)	Advantages	Disadvantages
<b>Water Paint - Water-borne (alkyd formula)</b>	\$0.03 - \$0.05	7.5-34 Months	9 - 36 Months	Air and pavement temperature above 32°F	275 - white 180 - yellow (beads - 8 lbs/gallon)	Inexpensive Quick-drying Longer life on low-volume roads Easy clean-up and disposal No collection of hazardous waste products	Short life on high-volume roads Subject to damage from sands/abrasives Bead application required Does not adhere as well to concrete Pavement must be warm or it will not adhere
<b>Epoxy</b>	\$0.20 - \$0.30	31-46 Months	36-48 Months	Air and pavement temperature above 50°F	300 - white 200 - yellow (beads - 25 lbs/gallon)	Longer life on low and high volume roads More retroreflective	Slow-drying Requires coning and flagging during application Heavy bead application required which will need to be cleaned off of roadway High initial expense Subject to damaged sands/abrasives
<b>Thermoplastic</b>	N/A	Data pending	36 - 72 Months	All temperatures	275 - white 180 - yellow	Long life on low and high volume roads Retroreflective No beads needed Any temperature for application	Subject to damage from sands/abrasives May suffer snowplow damage
<b>Tape w/o groove</b>	\$1.50 - \$2.65	25-95 Months	48 - 96 Months	Minimum temperature: Air-60°F Pavement - 70°F bituminous - 120° - 150°F	350 - white 250 - yellow	Highly retroreflective Long life on low and high volume roads Useful in high traffic areas Reduces worker exposure to road hazards because of long life	High initial expense Best when only used on new surfaces (not worth the expense to use on older roads) May suffer snowplow damage
<b>Tape with groove</b>	\$1.800 - \$2.95	25-95 Months	48 - 96 Months	Minimum temperature: Air-60°F Pavement - 70°F bituminous - 120° - 150°F	350 - white 250 - yellow	Highly retroreflective Long life on low and high volume roads Useful in high traffic areas Reduces worker exposure to road hazards because of long life	High initial expense Best when only used on new surfaces (not worth the expense to use on older roads) May suffer snowplow damage
<b>PolyUrea</b>	\$1.50 - \$2.00	36-72 Months	24-36 Months	Minimum temperature: Air-40°F Pavement - 40°F	725 - white 560 - yellow	Quick-drying Lower temperature for application Non-yellowing binder Good adhesion and retro readings on concrete Predicted life comparable to tape at less cost	Untested on asphalt in Utah

1. Based on decaying exponential trendline modeling of currently compiled retroreflectivity data.

2. Add \$0.30/ft for diamond grind grooving



**APPENDIX C: STATE PAVEMENT MARKING CONTACTS**

<b>State</b>	<b>Best Contact</b>	<b>Phone</b>	<b>Email</b>
Alabama	Kerry NeSmith		nesmithk@dot.state.al.us
Alaska	Jefferson Jeffers		jeff.jeffers@alaska.gov
Arizona	Maysa Hanna		mhanna@azdot.gov
Arkansas	Eric Phillips		eric.phillips@arkansashighways.com
ATSSA			
California	Atifa Ferouz	916-654-5032	atifa.ferouz@dot.ca.gov
Colorado	Charles Meyer		charles.e.meyer@state.co.us
Connecticut	Charles Harlow		Charles.Harlow@ct.gov
Delaware	Mark Luszcz		mark.luszcz@state.de.us
FHWA			
Florida	Mark C. Wilson		mark.wilson@dot.state.fl.us
Georgia	Andrew Heath		aheath@dot.ga.gov
Hawaii			
Idaho			
Illinois	Kyle Armstrong	217-782-2076	kyle.armstrong@illinois.gov
Indiana	David Boruff		dboruff@indot.in.gov
Iowa	Tim Crouch	515-239-1513	tim.crouch@dot.iowa.gov
Kansas	Michael Floberg		floberg@ksdot.org
Kentucky	Jeff Wolfe	502-782-5546	jeff.wolfe@ky.gov
Louisiana	Jody Colvin	225-242-4635	jody.colvin@la.gov
Maine	Stephen Landry		Stephen.landry@maine.gov
Maryland	Cedric Ward		cward@sha.state.md.us
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Montana	Roy Peterson	406-444-9252	roypeterson@mt.gov
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New Hampshire	William Lambert		wlambert@dot.state.nh.us
New Jersey	Chris Barretts		chris.barretts@dot.state.nj.us
New Mexico	Afshin Jian	505-827-5490	afshin.jian@state.nm.us
New York	Patrick Galarza	518-457-4599	Patrick.Galarza@dot.ny.gov
North Carolina	Chris Howard	919-661-3262	cbhoward@ncdot.gov
North Dakota	Clayton Schumaker	701-328-6906	cschumaker@nd.gov
Ohio	Jason Yeray	614-466-2168	jason.yeray@dot.ohio.gov

Oklahoma	Harold Smart		hsmart@odot.org
<b>State</b>	<b>Best Contact</b>	<b>Phone</b>	<b>Email</b>
Oregon	Eric Leaming	503-986-3610	eric.s.leaming@odot.state.or.us
Pennsylvania	Donald Krick	717 265-7558	dkrick@pa.gov
Rhode Island	Robert Rocchio		robert.rocchio@dot.ri.gov
South Carolina	Tony Sheppard		sheppardts@scdot.org
South Dakota	Christina Bennett		Christina.Bennett@state.sd.us
Tennessee	Jason Oldham		jason.oldham@tn.gov
Texas	Michael Chacon		michael.chacon@txdot.gov
Utah	John Leonard		jleonard@utah.gov
Vermont	Bruce Nyquist		bruce.nyquist@vermont.gov
Virginia	Harry Campbell	804-786-6374	Harry.Campbell@VDOT.Virginia.gov
Washington DC	Soumya Dey		soumya.dey@dc.gov
Washington	John Nisbet		nisbetj@wsdot.wa.gov
West Virginia	Cindy Cramer		Cindy.L.Cramer@wv.gov
Wisconsin	Linette Rizos	414-333-6234	linette.rizos@dot.wi.gov
Wyoming	Christina Spindler	307-777-4353	christina.spindler@wyo.gov

**APPENDIX D: STATE DOT WEB SEARCH AND SURVEY RESULTS \***

<b>State</b>	<b>Responded to Survey</b>	<b>Does State have a Pavement Marking Guide</b>	<b>Does it Consider Durability (Pavement ADT)</b>	<b>Does it Include Safety Considerations</b>	<b>Does it Include Climate Considerations</b>	<b>Does it Include Standard Specification Considerations</b>	<b>Active Research Projects Identified</b>
Airport Markings	-	Yes	✓	✓	✓	✓	✓
Alabama	-	No	-	-	-	-	-
Alaska	-	Yes	✓	-	-	✓	✓
Arizona	-	Yes	✓	✓	-	✓	✓
Arkansas	-	No	-	-	-	-	-
California	✓	Yes	✓	✓	✓	✓	✓
Colorado	-	Yes	✓	-	-	✓	✓
Connecticut	-	No	-	-	-	-	-
Delaware	-	Yes	-	-	-	✓	-
FHWA	-	Yes	✓	✓	✓	✓	✓
Florida	-	Yes	✓	-	-	✓	✓
Georgia	-	Yes	-	-	-	✓	-
Hawaii	-	No	-	-	-	-	-
Idaho	-	-	-	-	-	-	-
Illinois	✓	Yes	✓	-	✓	✓	-
Indiana	-	No	-	-	-	-	-
Iowa	✓	Yes	-	-	-	✓	-
Kansas	-	Yes	-	-	-	✓	-
Kentucky	✓	Yes	-	-	-	✓	-
Louisiana	✓	No	-	-	-	-	-
Maine	-	No	-	-	-	-	-
Maryland	-	Yes	-	-	-	✓	-
Massachusetts	-	No	-	-	-	-	-
Michigan	✓	Yes	✓	✓	✓	✓	✓
Minnesota	-	Yes	✓	-	-	✓	✓
Mississippi	-	No	-	-	-	-	-
Missouri	-	No	-	-	-	-	-
Montana	✓	No	-	-	-	-	-
Nebraska	✓	No	-	-	-	-	-
Nevada	-	No	-	-	-	-	-
New	-	No	-	-	-	-	-

State	Responded to Survey	Does State have a Pavement Marking Guide	Does it Consider Durability (Pavement ADT)	Does it Include Safety Considerations	Does it Include Climate Considerations	Does it Include Standard Specification Considerations	Active Research Projects
Hampshire							
New Jersey	-	No	-	-	-	-	-
New Mexico	✓	Yes	✓	-	-	✓	-
New York	✓	Yes	✓	-	✓	✓	-
No. Carolina	✓	Yes	✓	✓	✓	✓	✓
North Dakota	✓	No	-	-	-	-	-
Ohio	✓	Yes	✓	-	-	✓	-
Oklahoma	-	No	-	-	-	-	
Oregon	✓	Yes	✓	✓	✓	✓	✓
Pennsylvania	✓	Yes	✓	✓	-	✓	-
Rhode Island	-	No	-	-	-	-	-
So. Carolina	-	No	-	-	-	-	-
South Dakota	-	No	-	-	-	-	
Tennessee	-	Yes	-	-	-	✓	✓
Texas	-	Yes	✓	✓	✓	✓	✓
Utah	-	Yes	✓	-	-	-	✓
Vermont	-	Yes	-	-	-	✓	-
Virginia	✓	Yes	✓	✓	-	✓	✓
Wash. DC	-	No	-	-	-	-	-
Washington	-	Yes	✓	✓	✓	✓	✓
West Virginia	-	Yes	-	-	-	-	-
Wisconsin	✓	Yes	-	-	-	✓	✓
Wyoming	✓	No	-	-	-	-	-

- State practices Summary Table is based on readily available information from web pages and survey. Practices of states having more detailed pavement marking practices may be missing.

**APPENDIX E: LITERATURE SEARCH REFERENCES**

<b>Report Number</b>	<b>Title</b>	<b>Agency, Number and Year</b>	<b>Perf Data</b>	<b>Cost Data</b>	<b>Selection Criteria</b>	<b>Display Methods</b>	<b>New Products</b>	<b>Photos</b>	<b>Comments</b>
1	Assessment of the Durability of Wet Night Visible Pavement Markings: Wet Visibility Project Phase IV	Virginia VCTIR 12-R13 2013	H	Cost per yr per ft	H	H	No	H	3M High-Build Paint, 3M White Tape, 3M Thermoplastic, Ennis High-Build Paint, Ennis MMA, Epoplex Glomarc 90. On surface, grooved and rumble strips. Dry, 1 in/hr, 2 in/hr
2	WET NIGHT VISIBILITY OF PAVEMENT MARKINGS: EXECUTIVE SUMMARY	Virginia VTRC 05-CR4 2004	H	No	H	M	No	H	Latex Paint with Standard Beads, Latex Paint with Large Beads, Thermoplastic, Retroreflective Tape. Truck & car.
3	PAVEMENT MARKING VISIBILITY REQUIREMENTS DURING WET NIGHT CONDITIONS	Virginia VTRC 07-CR7 2006	H	No	H	H	No	H	Latex Paint with Standard Beads, Latex Paint with Large Beads, Profiled Thermoplastic, Wet Retroreflective Tape. Overhead lighting, glare, car & truck. Asphalt & Concrete.
4	Qualified Pavement Markings Inspection Technician- PowerPoint	Tech training manual	No	No	L	M	No	H	Training Manual. J6
5	Evaluation of Wet-Nighttime Delineation	Kentucky KTC-13-05 2013	No	No	Yes	L	No	L	Raised markers, thermoplastic, Wet-reflective tape & paint, rumble stripes. Great references
6	GUIDELINE FOR SELECTING MATERIALS AND STANDARD SPECIAL PROVISIONS FOR TRAFFIC STRIPING AND PAVEMENT MARKING	California Version 2 2011	L	No	M	H	No	No	thermoplastic, two-component paint, Recessed thermoplastic, enhanced wet night visibility with glass beads, rumble strips, flow charts

7	Colorado Experimental Feature	Colorado IM-0252-382 2009	M	No	No	No	No	No	Epoplex Glowmarc 90 Polyurea, epoxy, preformed plastic. Experimentatl Feature Report.
8	Alaska DOT Test Decks	FHWA-HRT-12-048 2013	M	Yes	L	L	No	H	Test decks. All-weather paint, Methyl methacrylate, tape, Modified urethane, Low-temperature acrylic paint, High-build acrylic paint, Polyurea, Preformed thermoplastic,
9	Arizona DOT Scanning Tour - Recessed Markers	Study 1302	M	No	M	L		H	Video useful for training
10	CalTrans Cost Data & Flow Charts		L	No	L	H	No	No	Wet-Night or Fog Area Visibility Concerns, Cost data, flow charts
11	Sunline Contracting		M	No	M	L	No	H	Promotional but good photos
12	WET NIGHT HIGH VISIBILITY DURABLE PAVEMENT MARKINGS	Alberta 2007	M	No	L	L	No	No	Abstract
13	EVALUATION OF WET-WEATHER AND CONTRAST PAVEMENT MARKING APPLICATIONS: FINAL REPORT	FHWA/T X-07/0-5008-2 2007	H	Yes	H	H	No	H	Polyurea, Thermoplastic, MMA, Tape 380WR, cluster beads, rumble stripe, Rain maker, BENEFIT-COST ANALYSIS, Cost per year of service, Concrete contrast data,
14	Reflecting on Highway Safety by Wendy Ealding, ASTM Guidelines	Newslette r	M	No	M	M	No	No	Profile markings are elevated above their base, in the form of "waffles," or ridges of extruded material
15	EPOXY REFLECTORIZED PAVEMENT MARKINGS	N Y, Demo	L	No	L	L	No	No	Epoxy specs for NY test section.
16	EPOXY REFLECTORIZED PAVEMENT MARKINGS	Michigan DOT	M	No	M	M	No	No	Report to Legislature, Rumble strip, tape, polyurea,

17	The Refinement of Drivers' Visibility Needs During Wet Night Conditions: Wet Visibility Proj Phase III	Virginia VCTIR 11-R20 2011	H	No	H	H	No	Yes	Ennis High Build in Rumble Strip, Epoplex Glomarc 90, 3M Tape,
18	Nighttime Visibility and Retroreflectance of Pavement Markings under Dry, Wet, and Rainy Conditions	Iowa No. 03-3857 2003	H	No	H	H	No	No	Flat tape, Raised tape, Wet weather tape,
19	All-Weather Pavement Marking System Gets Work Zone Test	FHWA Innovator Issue 30 May 2012	H	No	M	L	No	H	3M™ All-Weather Paint for work zones
20	Wet-Reflective Pavement Marking Demonstration Project	Iowa IHRB Project TR-597 2011	H	No	H	H	No	H	MMA, Tape, Thermoplastic, Epoxy, Waterborne, Hybridized Epoxy, Multi-Polymer, Urethane Epoxy, Polyurea
21	Thruway Authority introduces new reflective striping program	NY Thruway	H	No	M	L	No	No	"Recess Triple Drop" used by the NY Thruway Authority's Highway Design Bureau.
22	Florida Wet Weather Demo Project	BDI91 2009	H	No	H	H	No	H	Test deck of various wet-weather pavement markings.
23	Nighttime Visibility of Prototype Work Zone Markings Under Dry, Wet-Recovery, and Rain Conditions	TTI	H	No	M	L	No	No	Highways for LIFE Technology Partnerships Program Temporary Wet-Weather Pavement Markings for Work Zones project. Three prototype optics-on-paint marking systems employing high refractive index dual-optics drop-on elements were evaluated at night under dry, wet-recovery (immediately after rainfall), and rain conditions.

24	Durable, Retroreflective Pavement Markings & Markers Increase Visibility for Drivers In Wet, Night Conditions	Virginia Synthesis No. 20 2009	H	No	M	M	No	No	<p>Challenges to improving retroreflectivity performance:</p> <ul style="list-style-type: none"> <li>•Type of material and installation methods.</li> <li>•Service life, durability and cost of durable materials.</li> <li>•Damage to materials by forces such as weather and traffic wear.</li> <li>•Setting minimum reflectivity standards (as cited in the MUTCD 2003 and/or by state DOTs).</li> <li>•Developing strategies and tools to measure retroreflectivity.</li> <li>•Marking and marker installation issues including increasing shortages of skilled workers for installation and maintenance.</li> <li>•Location of installation, climate and traffic load on roadway.</li> <li>•Funding and standards for maintenance.</li> <li>•Many new technologies entering the market, each requiring evaluation.</li> <li>•Environmental regulations.</li> <li>•Product acceptance and approval.</li> <li>•Driver needs (including differing needs based on driver age and time of day).</li> <li>•Vehicle type and the visibility concerns of trucks vs. cars.</li> </ul>
25	Performance Evaluation of Pavement Markings Under Dry, Wet, and Rainy Conditions in the Field	TRR No 1877 2004		No	M	L	No	No	<p>A largebeaded permanent pavement marking and two types of patterned pavement marking tapes, one with high-index beads and the other with mixed high-index beads were evaluated.</p>

26	An Investigation of Longitudinal Pavement Marking Retroreflectivity and Safety	TTI 2012	M	No	M	M	No	No	White edge lines (WEge), white lane lines (WLane), yellow edge lines (YEdge), and yellow center lines
27	Innovative Products and Practices for Pavement Marking	APWA 2012	H	No	M	L	No	H	Excellent photos. Blended Beads for single drop, Double Drop, High Performance Beads
28	AN INVESTIGATION INTO THE PREDICTIVE PERFORMANCE OF PAVEMENT MARKING RETROREFLECTIVITY MEASURED UNDER VARIOUS CONDITIONS OF CONTINUOUS WETTING	Texas A&M 2005	H	No	M	L	No	H	Waterborne Paint Ennis Paint III Waterborne Paint Polyurea, EpoPlex, GloMarc 90, Epoxy EpoPlex, Alkyd Thermoplastic Ennis Paint, Tape, Polyurea EpoPlex GloMarc 90, Methyl Methacrylate,
29	Nighttime Visibility of 3M AWP and 3M 380WR ES Durable Tape under Dry, Wet, and Rainy Conditions	Ohio 134563 2012	H	No	M	L	No	no	Proposes 3M all weather paint (AWP) and 3M 380 wet retroreflective (WR) extended season (ES) durable tape, and extruded thermoplastic for new asphalt surfaces. Remove raised plowable markers.
30	COST 331 Requirements for Horizontal Road Marking	European Co-operation in the Field of Scientific and Technical Research	M	No	M	L	No	No	European country's guidelines
31	Evaluation of Profiled Pavement Markings	U of Alabama 2003	H	No	M	L	No	No	Profiled markings, used water truck,
32	EVALUATION OF INLAID DURABLE PAVEMENT MARKINGS IN AN OREGON SNOW ZONE	Oregon DOT 2006	M	No	M	L	No	H	Dura-Stripe, Waterborne Paint, Permaline, 3M Tape

33	Pavement Marking Photometric Performance and Visibility Under Dry, Wet, and Rainy Conditions: Pilot Field Study	TRR 1973 2014	M	No	M	M	No	No	Four levels of material performance were created by a systematic reduction of the retroreflective efficiency of a single wet retroreflective tape construction.
34	Safety Evaluation of Wet Reflective Pavement Markers	FHWA-HRT-15-065	H	Yes	Yes	H	No	No	Wet-reflective markings paint, tape, or thermoplastic material. Nighttime wet-weather crashes, Nighttime crashes, Wet weather crashes, Run-off-road crashes, head-on crashes, Sideswipe-opposite-direction and same crashes, in Minnesota, North Carolina, and Wisconsin. <b>Reductions in crashes that are statistically significant for injury and wet-road crashes. B/C = 1.45 to 5.44</b>